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NAVWEPS REPORT 7289

SMEAR-CAMERA TECHNIQUES (U)

18 AUGUST 1960

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U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

SMEAR-CAMERA TECHNIQUES

By:

T. P. Liddiard, Jr. and B. E. Drimmer

Approved by: Chief, Explosion Dynamics Division

ABSTRACT: The various photographic systems and techniques used at NOL and other laboratories in conjunction with rotating-drum and rotating-mirror smear cameras are briefly discussed, and typical samples are shown of records obtained by such means. These techniques greatly increase the usefulness of such sweeping-image cameras in detonation and shock-dynamics research.

PUBLISHED OCTOBER 1960

EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

The authors have presented a summary of photographic techniques applicable to smear cameras used in detonation and shock-dynamics research. The report was prepared for presentation at the 5th International Congress on High-Speed Photography, October 16-22, 1960; Washington, D. C. It is printed as a NAVWEPS Report to afford a wider and earlier distribution than is possible as a chapter in the proceedings of the Congress.

The examples cited in this report were accumulated from work performed at NOL over the past ten years under the sponsorship of the Navy Bureau of Ordnance and in part, the U. S. Atomic Energy Commission through the University of California Lawrence Radiation Laboratory, Livermore, California. In the more recent years the work was performed under Explosives Applied Research Task 301-664/43006/08, and Project LACE, Task NOL 260.

The statements contained herein which are believed to be correct are the responsibility of the authors and are not to be considered as binding on the Laboratory.

W. D. COLEMAN
Captain, USN
Commander

C. J. Aronson

C. J. ARONSON
By direction

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SMEAR-CAMERA TECHNIQUES

ABSTRACT: Various techniques have been developed which greatly increase the usefulness of the sweeping-image smear camera in detonation and shock-dynamics research. When self-luminosity is insufficient, several methods are used to enhance the light, e.g. Scotch tape on explosive surfaces, air or argon gaps, etc. When required, external light is supplied by exploding wires, explosive flash lamps, etc. The sharp change in the intensity of light reflected from the surface of high-reflecting, opaque materials is used to record the arrival of shocks at the surface. When the reflectivity of the test surface is low, a covering of thin aluminized-plastic film is used, clearly signaling shock-arrival times. Very weak disturbances are observed by schlieren techniques, using either transmitted or reflected light. Multiple slits, or grid systems of various configurations can be used to increase the quantity of recorded information. "Light pipes" of optically-clear filaments can be used to transmit light signals from points inaccessible to direct observation, to positions of alignment within a single slit, or to other convenient configurations. Other techniques are described, such as velocity-synchronization, shadowgraphing, time-dependent spectroscopy, and the use of color film.

I. Introduction

In a recent article (Ref. 20) B. Brixner described the construction and performance characteristics of the most advanced form of smear camera in use today. Such cameras and their more simple predecessors, have played a significant role, especially in the last two decades, in the study of certain transient phenomena, such as are observed in detonations, shock dynamics, explosive loading, etc. The increased utility of these cameras is attested to by the fact that the authors have been consulted on numerous occasions on applications of these instruments to various research problems in these fields. We have found it helpful to our colleagues and to ourselves to summarize in one short article the different methods, systems, and techniques that have been found useful in increasing the versatility of this instrument. It is to be emphasized that many of these methods are not "new" but are merely applications to smear photography of well-known photographic, optical, or shock techniques.

Basically, a smear camera is an instrument which records continuously (as contrasted with intermittent recording, as in a framing camera) the changes of light intensity along a line, as a function of time. Using a detonating cylinder of explosive as an example, the modes of employment of the camera can be divided into three groups, according to the orientations of the camera slit and optical axis to the axis of the explosive charge: (1) Velocity measurement: slit parallel to cylinder axis; camera optical axis normal to cylinder axis; (2) Time-of-arrival measurement: slit perpendicular to cylinder axis; camera optical axis parallel to cylinder axis; (3) Profile shot: slit and camera optical axis perpendicular to cylinder axis. It is this fundamental property of resolving in time the changes of light intensity along the slit that makes the camera so useful, as will be seen below.

Generally, the method of employment of the camera is rather straightforward, as in the determination of the detonation rate in a cylinder, or a slab of explosive. Even here a few "tricks" can be applied which significantly improve the quality of the record. These improvements often produce acceptable records yielding data that otherwise would not have been obtained. The problem in smear camera photography can be simply stated: how can one cause a phenomenon, such as a shock wave, to produce light intensity changes (and thus signal its location) of sufficient magnitude to permit the camera to record the change? Obviously, if the slit is aligned in the desired manner along the path to be followed by the phenomenon, a position versus time record is obtained, which on analysis can produce highly significant information. In this article the various systems and techniques used at NOL and other laboratories in conjunction with rotating-drum and rotating-mirror smear cameras are briefly discussed, and typical samples are shown of records obtained by such means.

II. Simple Systems without Auxiliary Light Sources

When the phenomenon is self-luminous, as in the detonation of an explosive, the light from the detonation front itself is used. The resulting record, however, frequently leaves much to be desired, especially if the luminosity is low. Considerable improvement in the quality of the record can be made by the simple expedient of pressing a transparent, plastic, pressure-sensitive tape (e.g. Scotch tape) against the explosive charge, along the line to be viewed by the camera. If a series of fine, shallow lines (e.g. 0.005-inch deep by 0.010-inch wide) are scratched into the explosive beneath the tape, a series of sharp, bright dots are recorded, simplifying the record-reading problem. A comparison between the results obtained with a bare explosive charge (Figure 1) and with a charge employing tape and scratches (Figure 2) shows clearly the benefits to be obtained by the latter technique.

Often a wave phenomenon (e.g. the arrival of a shock-wave at a free surface) does not produce a luminosity of acceptable intensity. Increased luminosity can be obtained by using a material which, when shocked, produces the desired results. Two of the most frequently used light "intensifiers" are argon and air. The gas is placed in very thin channels, typically about 0.003-inch deep, within, or on the surface of the test specimen. When the shock traverses this channel a brilliant, sharp light of short duration is emitted. Thus, a series of such channels, judiciously placed, could produce highly accurate space-time data. This method has found a great deal of use in obtaining experimentally determined equation-of-state data for solids for pressures ranging into the hundreds of kilobars (Ref. 1).

A variant of the shocked-argon system is to use plastic microballoons glued to the surface under observation. This method has also found utility in equation-of-state work on solids (Ref. 2).

III. Light-Reflection Systems

For events that are not self-luminous, some external, intense light source is required, such as an exploding wire (Ref. 3), shocked argon gas (Ref. 4), etc. The light, reflected off the surface to be studied, acts as a mass-less probe, interposing no interference with the phenomena being observed. Apparently first used in 1953 (Refs. 5, 6, 7), we have found this system to be the basis of one of the most useful techniques to be employed with the smear camera. For example, Figure 3 shows the arrival of explosive-generated shock waves at the free surfaces of aluminum and steel. The sharp change in light intensity clearly and instantaneously depicts the arrival of the shock wave at the surface. The delicacy of this system can be appreciated by noting the results obtained with steel, where the pairs of parallel lines are interpreted to indicate the arrival at the free surface of the faster-moving elastic wave ahead of the slower-moving plastic wave.

We have expanded the light-reflecting technique, for use with non-reflecting (or poorly reflecting) materials, by employing a thin (0.0006 inch) aluminized plastic (Mylar) film. By placing the 0.0001-inch thick aluminum layer against the surface to be studied, and viewing through the transparent plastic, such surfaces are rendered highly reflective. Attachment of the plastic film to the surface is accomplished by the simple expedient of adding a drop of water between the surface and the film, then pressing the film gently to remove the excess water. (The addition of a small amount of a surface-tension-diminishing detergent to the water is beneficial in this connection.) This system has found considerable use in this Laboratory in studying such processes as the build-up to detonation of an explosive under shock loading (Refs. 8, 9).

IV. Shadowgraph Systems

When reflected light is not practical, nor desirable, ordinary shadowgraph techniques are used. For example, Figure 4 contains a shadowgram of the detonation of a thin slab of explosive immersed in water, from which highly accurate space-time data can be obtained. If the detonation wave moves normal to the explosive-water interface, by extrapolating the resulting water-shock velocities back to that interface, proper data can be obtained to permit a calculation of the Chapman-Jouguet pressure of the explosive (Ref. 10).

A variant on this scheme is to place the light source and the camera on the same side of the phenomenon under study. Behind the experimental subject is placed some highly-reflecting material which is viewed by the camera. As the experiment progresses the reflected light is modified (or even extinguished) by either a shadow or a light-refracting mechanism (such as a shock), and thus space-time data are obtained. Various light-reflecting systems have been used successfully, such as mirrors or wires (Ref. 11). (Scotch-Lite Reflectors have been used in framing-camera shadowgraph photography; the authors have found no references to its use with a smear camera, but can see no reason why it should not be applicable.)

When exceedingly small changes in light intensity are encountered, schlieren light systems are useful (e.g. Ref. 12). We have used it for example to photograph the extremely weak shocks transmitted in Plexiglas by an exploding wire (Figure 5). In a similar manner, by placing the entire optical system (light source, camera, knife edge, etc.) on the same side of the subject, a schlieren picture with reflected light can be obtained. We have recorded very low-amplitude, low-velocity waves in solids in this manner.

Streak interferometry is another variant of shadowgraph technique which can be a powerful tool for studying transient phenomena (Ref. 13).

V. Multiple-Slit Systems

Normally, a smear camera records events occurring along a single line: the line immediately behind an exterior slit (i.e. a slit located at the phenomenon) or else the line along the projected image of a slit that is located at the camera itself. Increased information can often be obtained by the simultaneous use of several slits. These slits can be parallel or crossed, continuous or discontinuous, the exact configuration depending on the desired results. Thus five parallel slits were used in Reference 1 to obtain simultaneously data of shock-wave arrival over an area (rather than along a single line).

Discontinuous, parallel slits are sometimes more convenient, as shown in Figure 6 where eleven discontinuous "slits", each consisting of 25 points, were used to record the formation of a Mach wave in Plexiglas formed by the collision of two regular shocks (Ref. 9).

Multiple slits need not necessarily be parallel; for selected purposes one can even have them intersect one another. In Figures 7 and 8 are shown smear-camera photographs showing the arrival of a detonation wave at the face of an explosive plane-wave generator. In Figure 7 five discontinuous slits plus one continuous one intersect at the center of the face of a four-inch diameter generator (which is viewed through a 0.25-inch thick glass plate placed 0.010 inch away from the generator face). The resulting dynamic record permits a simple analysis of the simultaneity of the time-of-arrival of the detonation front at the generator face. Figure 8 shows the results obtained in a duplicate experiment when using three continuous, intersecting slits.

VI. Miscellaneous Systems

Upon occasion it is desired to observe the arrival of a shock (or a detonation) wave at a point not directly observable by the camera. Mirrors are naturally used in this case; however, occasions arise when even these cannot serve the purpose. We have found that light pipes (Ref. 14) of 1-mm diameter glass rods gave acceptable signals (Fig. 9), thus permitting the camera to record time-of-arrival data at normally-inaccessible points.

When the motion of a phenomenon is essentially uniform the smear camera can be modified to produce a "still" picture. This is done in a relatively simple manner by matching the writing speed of the camera with the speed with which the image is displayed on the film (Ref. 15). Thus in Figure 10 we have a "still" picture of a slab of explosive detonating in air. This technique has the salutary effect of increasing the time of exposure of the phenomenon, and thus finds occasional use in recording selected steady-state phenomena that emit only low-intensity light. A variant of this technique has been used at this Laboratory to measure fragment velocities (Ref. 16). In this method the anticipated velocity is approximately matched and the flying fragment is recorded as it passes between the drum camera and three lighted slits. This produces a photograph with three exposures, which by suitable analysis provides an accurate measure of the fragment velocity.

The simple smear camera can be readily converted into a spectrograph by placing a transmission grating or a prism before the camera lens, using the camera slit as the spectrograph slit. These time-dependent spectra could then be converted to temperatures (e.g. detonation temperatures) by appropriate calculations. For highly luminous phenomena, such as an electrically exploded wire, such spectra are relatively easy to record (Ref. 17). The light from shaped-charge jets can also be recorded and analyzed by this means (Ref. 18). For phenomena emitting light of lower intensity, velocity synchronization permits longer exposures with resulting acceptable spectrograms (Ref. 15).

Finally, the use of color film has added another dimension to the smear camera. At NOL an unambiguous change was recorded in the wave length of light reflected from a metal free-surface when a shock wave reached the surface from within the metal (Ref. 19). (A color slide of this phenomenon was shown at the 5th International Congress on High-Speed Photography; October 1960; Washington, D. C. Since the significant features of this photograph would be lost in black-and-white reproduction, no copy was included for this publication.) Exploitation of the potentialities of this new tool has only begun!

In conclusion we would like to make clear that the above discussion was not designed to be a comprehensive study of the history, theory, and practice of smear-camera photography. Selected references, generally of the more recent (and presumably of the more advanced) vintage have been cited more as guides than to establish precedence. It is hoped that such a short summary will serve not only as a useful reference to aid the beginner in learning and applying smear-camera photography, but will also serve as a stimulus to the more advanced practitioner to develop additional techniques, making even more useful this highly versatile tool.

Finally, the authors wish to acknowledge with gratitude the many helpful suggestions and the guidance furnished by Dr. S. J. Jacobs of this Laboratory.

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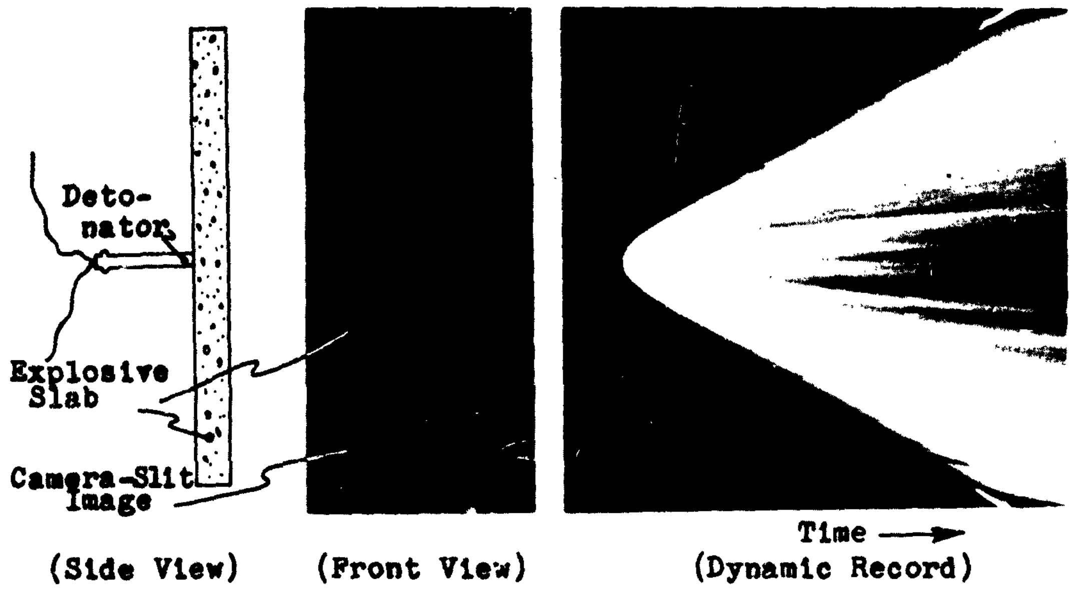

Figure 1. Arrival of detonation at the bare front surface of an explosive slab initiated at mid-position of the rear surface.

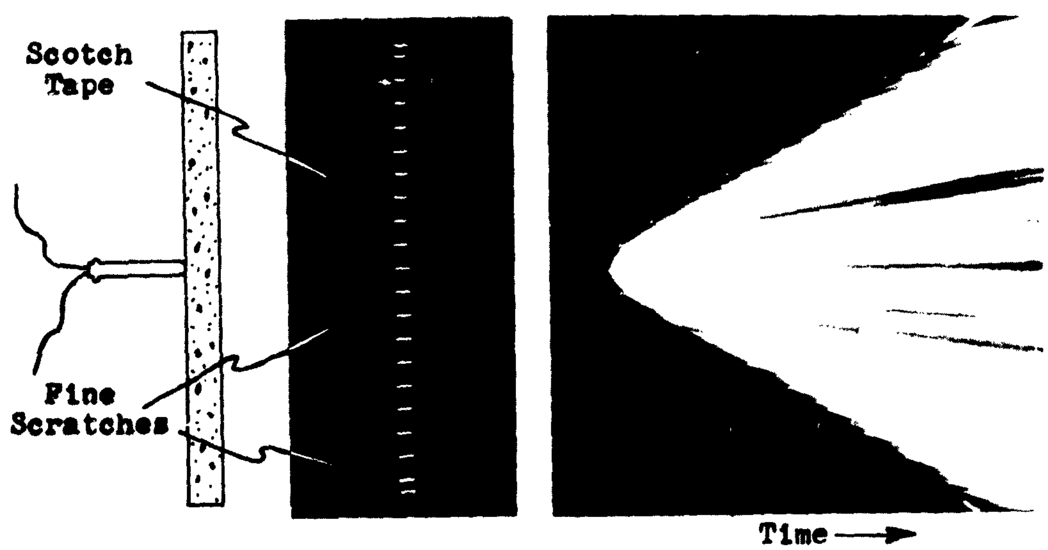

Figure 2. The same experiment as in Figure 1, except that fine reference lines (retouched above for publication purposes) were scratched on the front surface of the charge, perpendicular to the slit, and Scotch tape was pressed onto the charge over this region.

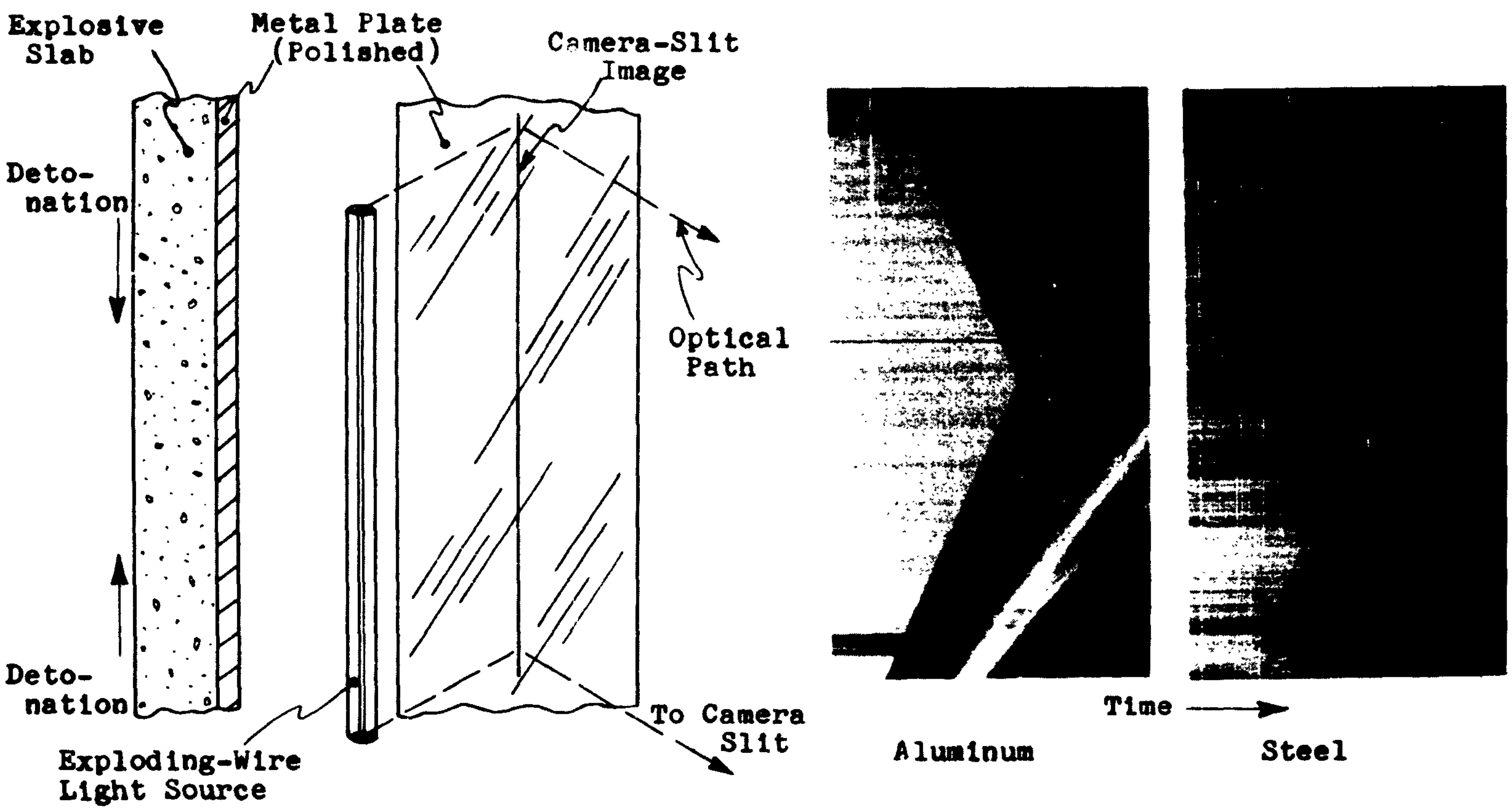

Figure 3. Reflected-light technique revealing the arrival of two colliding shock waves at the surface of a metal plate. The shocks were generated by two grazing detonation waves as shown in the figure at the extreme left.

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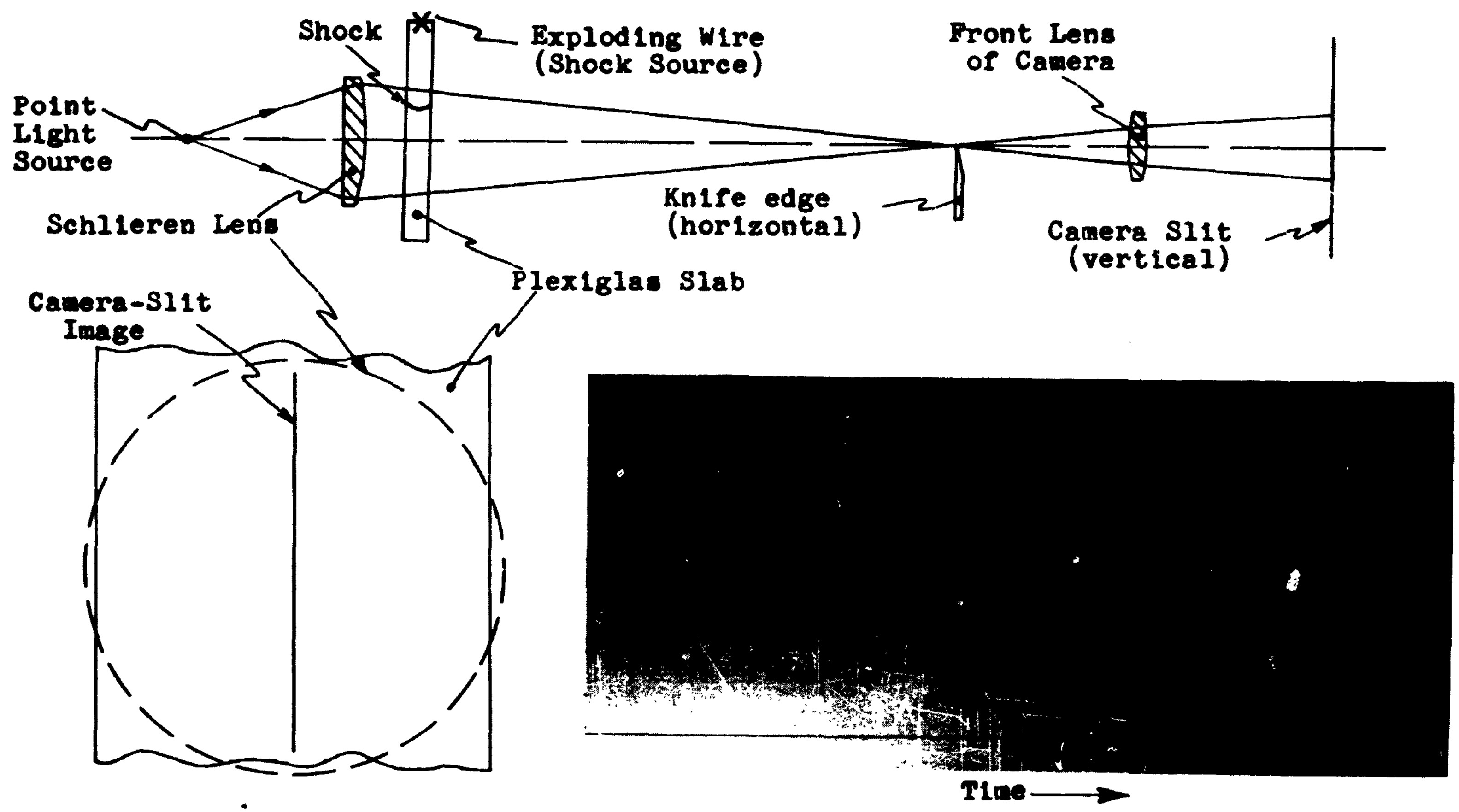
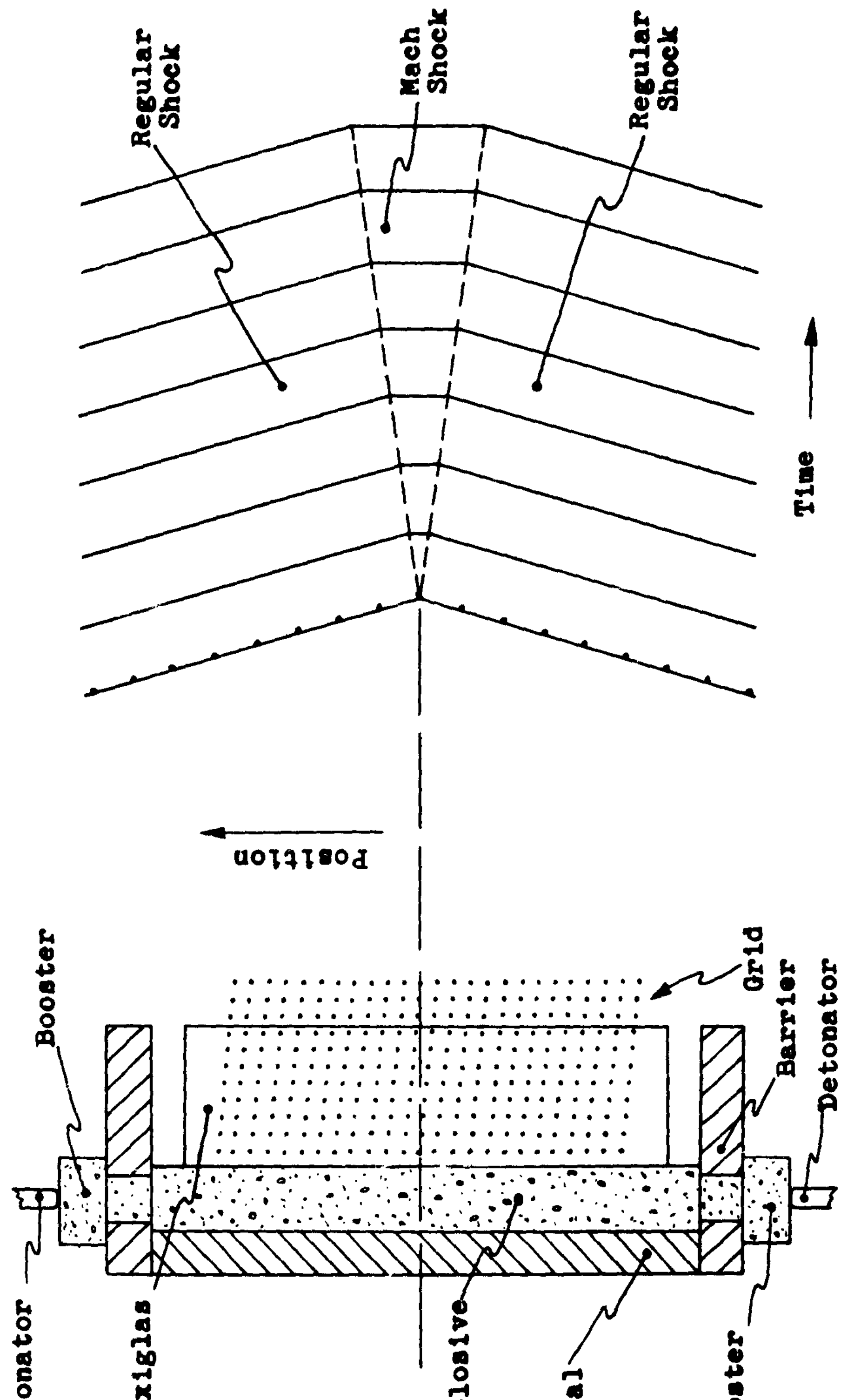


Figure 5. A smear-camera schlieren photograph of weak shock waves generated in Plexiglas by an exploding wire. Such waves are too weak to be recorded by the shadowgraph technique of Figure 4.



Traces Through Recorded Points of Figure 6(c).
6(b)

Experimental Set-up
6(a)

Figure 6. Use of a Point-Grid System in Smear Photography: Observation of a Mach Shock formed in Plexiglas by collision of two Regular Shocks.

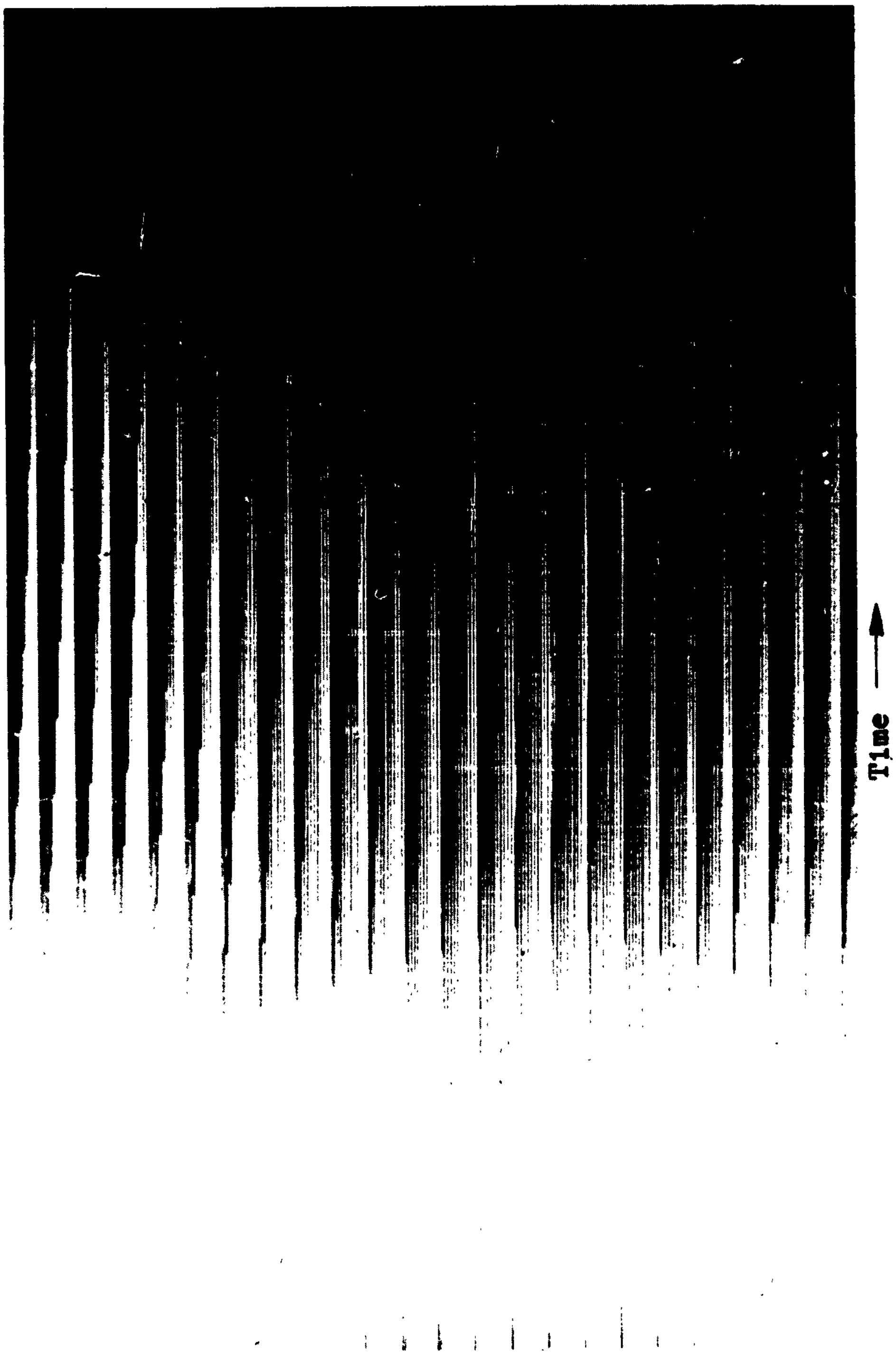
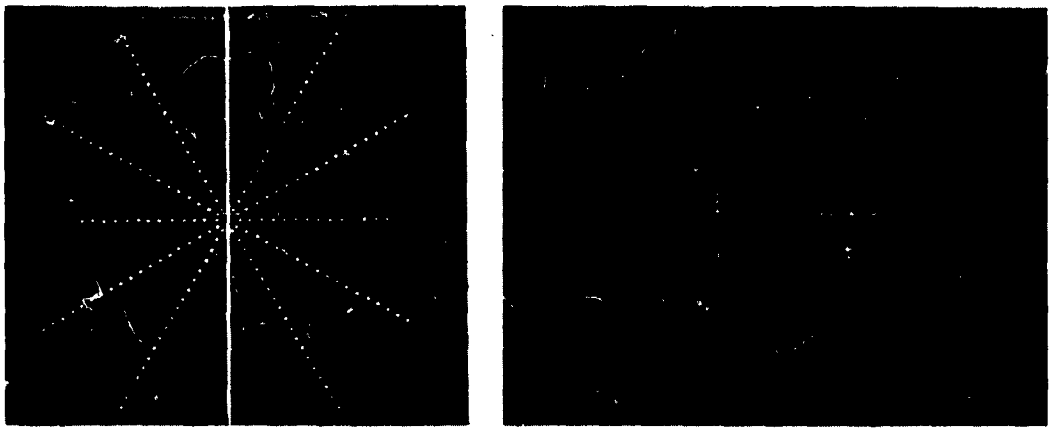


Figure 6(c). Record obtained from back-lighted experiment of Figure 6(a).



Still　　　　　　Time ⟶

Figure 7. Use of discontinuous, crossed, multiple slits to observe essentially simultaneous arrival of detonation front on face of a plane-wave generator. (Slits located at camera).

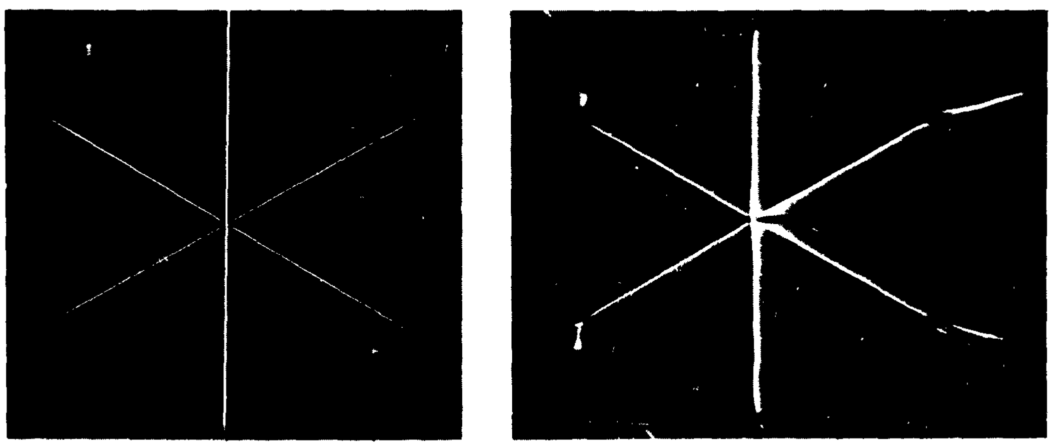


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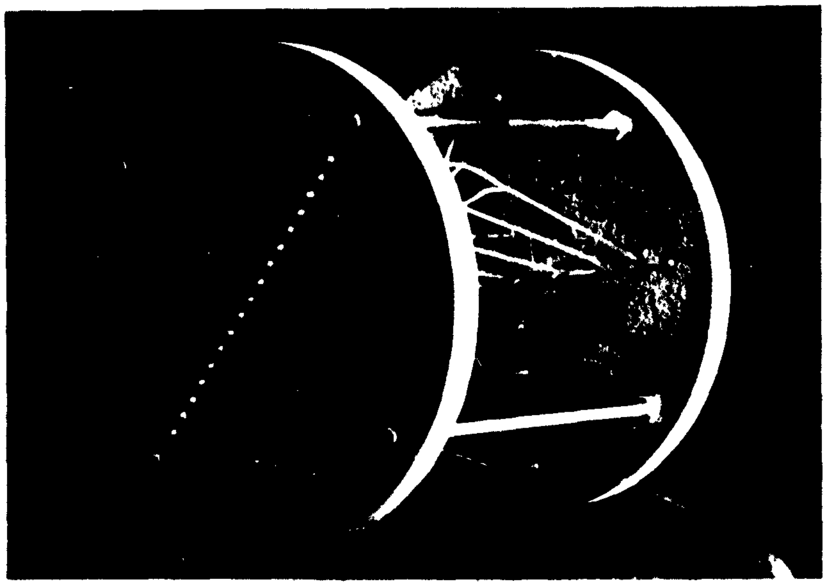
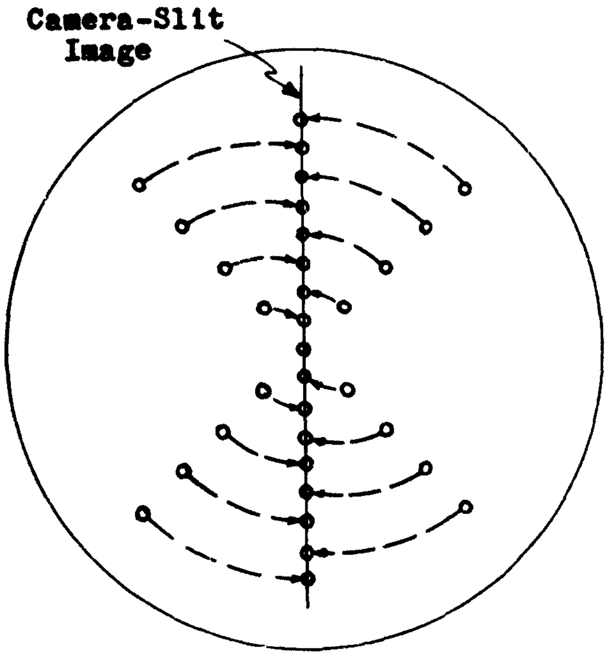
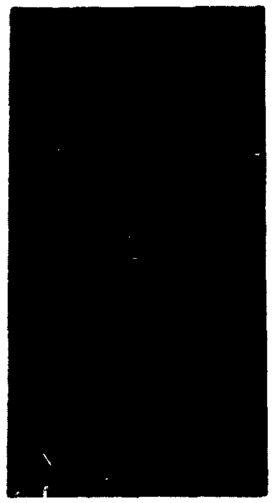
Figure 8. Use of continuous, crossed, multiple slits in repeat experiment of Figure 8.



(a) Light-pipe Fixture

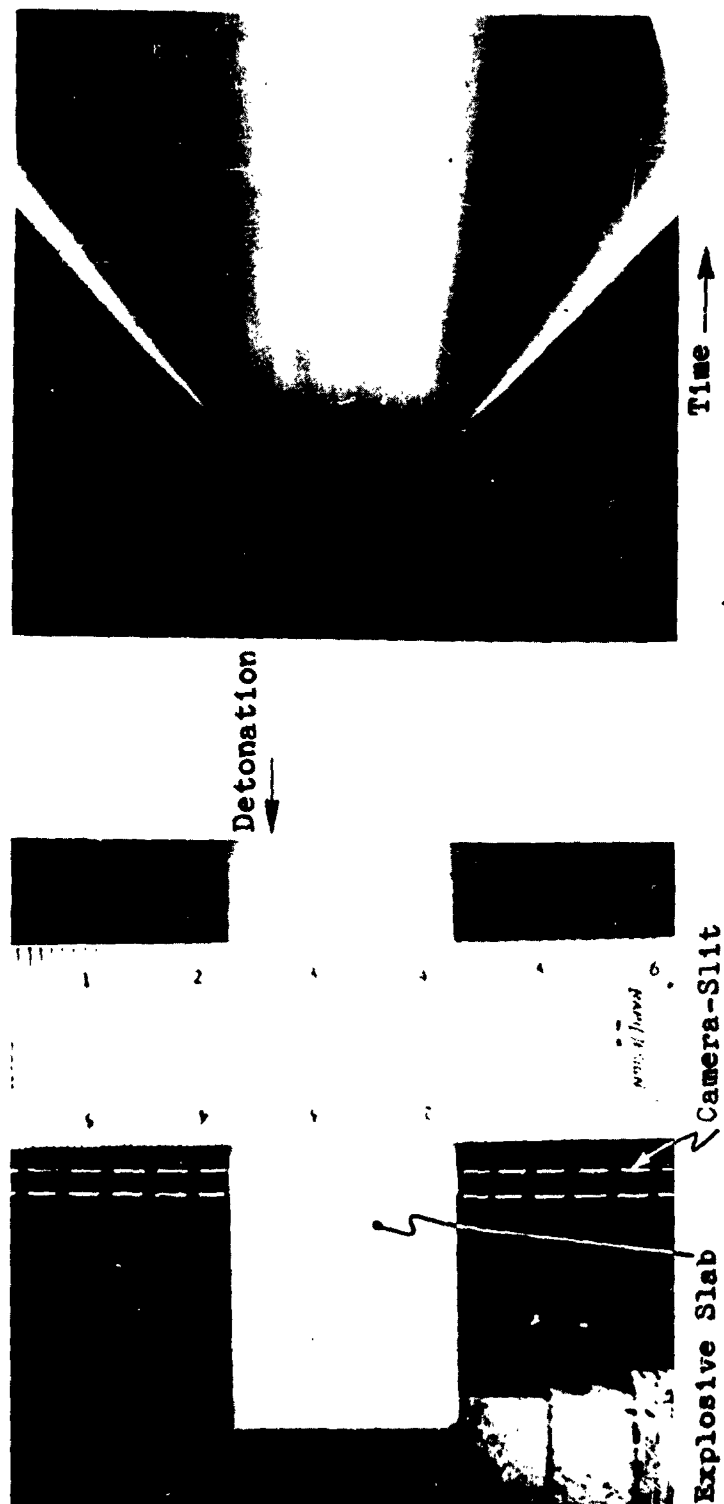




(c) Smear Record

(b) Seventeen light pipes, in form of a cross on the face of the fixture, aligned to a straight line on side of fixture facing camera.

Figure 9. Feasibility study of light-pipe application in smear photography: arrival of a detonation wave on the face of a plane-wave generator.



(By velocity synchronization, time is thus equivalent to distance along length of explosive slab).

Figure 10. Velocity-synchronized smear record of a slab of explosive detonating at constant velocity in air.